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Wind loads on stand-off photovoltaic systems on pitched roofs

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ABSTRACT

Stand-off photovoltaic systems are a popular measure for retrofitting of existing pitched roofs. Panels are generally mounted parallel to the existing roof coverings, usually roofing tiles. Full scale and wind tunnel experiments have been performed to determine the net uplift loads on these systems, which can be applied to calculate the loadbearing system. In the wind tunnel, the effect of distance between panel and roof has been investigated. Results show that loads can be expected that are substantially lower than the external loads on the roof surface, as given in wind loading standards. The effect of distance between PV system and roof surface is relatively small. The loads on the underlying roof are not significantly higher or lower compared to the case without system.

1. Introduction

There is a considerable growth in solar energy products mounted on buildings. Roofs, both existing and new, have a great potential in supporting these products. To support photovoltaic (PV) panels on pitched roofs of existing buildings, mainly stand-off systems are applied. These systems are mounted above the existing roof covering, such as roofing tiles. Design data are available for some types of installations but there is a scarcity of published information regarding the design wind loads on stand-off PV modules. The wind loading on these systems will be generated by a combination of the wind blowing over the top surface of the module and the wind blowing through the gap between the underside of the module and the existing roof, giving a net pressure over the panels. This net pressure is influenced by the shape, pitch and dimensions of both panel and roof, by the distance between roof and panels, and by the presence of gaps between the panels installed. Some general guidelines for calculation of wind loads on stand-off PV systems on pitched roofs are given in recent guidelines, such as NVN 7250 (NEN, 2007) and BRE Digest 489 (Blackmore, 2004) or Önorm 7778 (Önorm, 2011). These provisions have been based on very few available full scale and wind tunnel measurements (Tieleman et al., 1980) and an interpretation of design values given in current building codes. Backgrounds are described in (Geurts and Van Bentum, 2007). The results from these studies are appropriate for a limited range of roof forms. These data are also assumed to be very conservative, and hence also being uneconomic in many cases. Also, the studies available do not cover the situations occurring nowadays.

To provide more reliable wind loading data, both a full scale and a wind tunnel test have been set up to investigate the wind loading on these systems. This paper gives a description of both tests, results are compared and discussed.

2. Test site

A full-scale experiment was carried out over the period of one year, including the storm season. Fig. 1 shows the plan of the site of the full-scale house on which full scale data were measured, and which was modelled in the wind tunnel experiment. A view of the house from the southwest is given in Fig. 2. This house has a roof pitch of 42° and is built into the side of a dyke. For this experiment two 'dummy' PV modules were mounted on the house. The fetch to the southwest and west (the prevailing wind directions) is generally flat and open with few obstacles upwind. Wind induced pressures were measured on the top and bottom surfaces of the photovoltaic (PV) panels. Measurements were performed simultaneous with the on-site wind speed and direction. The photovoltaic panels were represented by two wooden panels with a size typical for PV panels. The length of the panels used is 1.60 m; the width is 0.80 m. The thickness of the wood in the panels is 18 mm. This is more than the size of glass panels, used for PV, which is usually about 3 mm. For the wind loading, this is assumed to be of minor importance. The frame applied was taken from a PV panel. The mounting system applied leaves a distance of about 150 mm between the roofing tiles and the panel. Panel 1 was attached to

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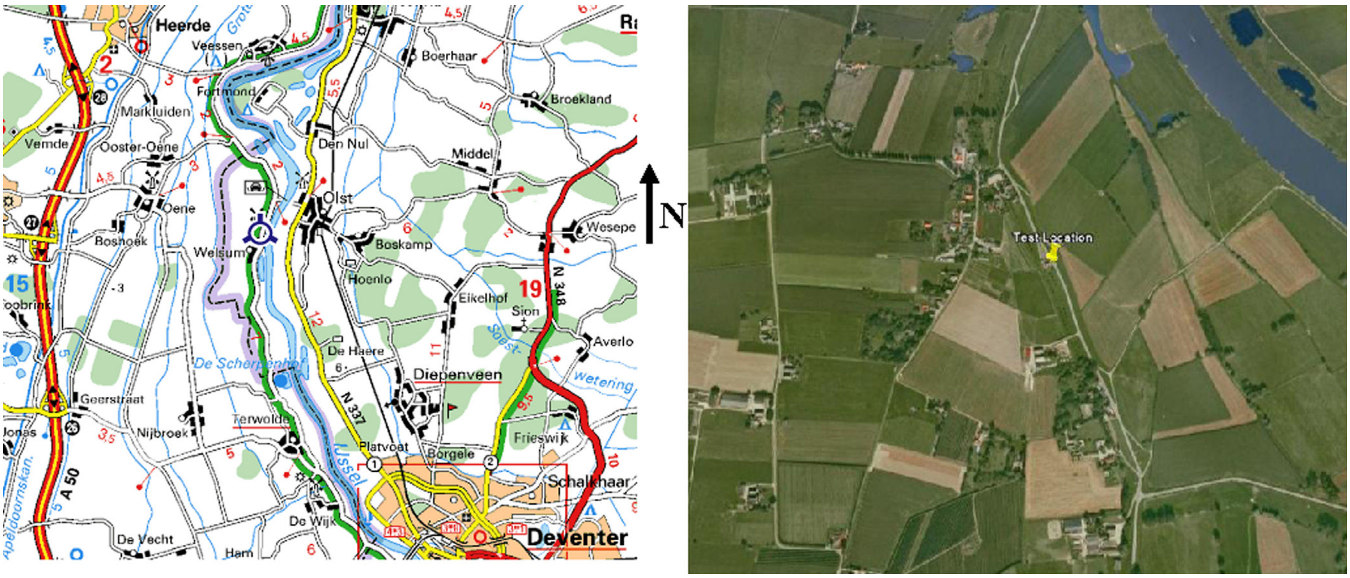

Fig. 1. Map and image (source: Google Earth) of the test site.

Fig. 2. View of the experiment from the west.

the southern slope of the roof as shown in Fig. 3A. A wind direction of 150° relative to the true north corresponds to wind perpendicular to this face. Panel 2 was fixed to the slope of the roof at the western side (Fig. 3B) for which a wind direction of 240° relative to the true north is perpendicular to the face. In this study, the approach flow wind directions are defined relative to the north façade; wind normal to this façade had a direction zero degrees. In Fig. 4, a sketch of the house and dike is given, together with the definition of approach wind directions, used in this paper.

3. Measurements

3.1. Full scale measurements

Wind induced pressures were measured simultaneously at the top and the bottom of the wooden panels. Differential pressure transducers, of the type Honeywell 163PC01D36, were used to measure the difference between the pressure on the location of the pressure tap and a reference pressure, obtained at a reference pressure location at ground level to the west of the test house. A total of 12 pressure taps were used, each connected to a transducer. Pressure taps in the panels were connected to the transducers through plastic tubes with an internal diameter of 10 mm. A calibration system measured a zero-pressure signal automatically after every run, which was used to correct for possible drift in the transducers over time.

Fig. 3 shows the measurement locations on the panels, positioned along the vertical centre line of the panels. Top and bottom pressures were measured separately on three positions at the top and bottom surface of each panel. Pressure transducers were mounted in metal boxes, with a maximum tube length between pressure tap and transducer of 1.5 m.

The wind speed and wind direction were measured with a cup anemometer and a directional vane at 10 m height above the field level, to the west of the house, see Fig. 2. The data were gathered in runs of 10 min length. Both the wind speed and pressures were determined with a sampling rate of 10 Hz.

Average values of both wind speed and pressures of every 10 min run were saved. When the mean wind speed of this 10 min-period exceeded a threshold, the raw data were saved for further analysis. This threshold has been set to 7 m/s, which was assumed low enough to gather a sufficient number of data during the test period. All data were grouped in wind direction intervals. Due to malfunctioning of the wind vane, the wind direction data measured on site could not be used. Instead, the directional data of the nearby meteorological station Heino have been used. This station provides 10 min mean wind directions every 6 h in 10-degree increments.

The data have been analysed stepwise. After removing suspicious data records with unexpected peaks or very non-stationary properties, all time series with a 10-min mean wind speed of more than 7 m/s have been saved. These time series were categorised in wind direction classes with 10° increments, as given by the meteorological station Heino, thus giving 36 sets of data. The number of data available differs within the different wind direction intervals. To perform a proper statistical analysis, for this experiment, a minimum required number of 32 time series of 10 min has been chosen. A total of 13 out of the 36 wind direction intervals had sufficient data records available. To obtain a sufficient number of time series for other wind directions, some wind direction intervals have been combined into larger intervals. In this way, results over approximately all wind directions could be generated. Table 1 provides an overview of available full scale data.

All pressure time series have been turned into pressure coefficients, using the 10-min mean wind speed, v_{10}, at 10 m height, as measured on site. This gives time series of the pressure